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Spin Observables in Consistent Relativistic Models of $(e, e'p)$ and (γ, p) Reactions*

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ABSTRACT

Single nucleon knockout reactions must be described in a consistent framework in order to extract information about nuclear structure and reaction mechanisms. Consistent relativistic models for the direct knockout contribution to the $(e, e'p)$ and (γ, p) reactions have been developed and used previously to examine existing momentum distribution and cross section data for the two reactions[1]. We present results of calculations of spin observables obtained from these models of $(e, e'p)$ and (γ, p) reactions. For the $(e, e'p)$ reaction we consider the importance of the choice of kinematics and show that perpendicular kinematics result in distributions with relatively large cross sections and comparatively large polarizations. In the (γ, p) reactions the photon asymmetry and proton polarization are not very sensitive to changes in model ingredients when the incident photon energy is less than 100 MeV. For higher energies these observables show increasing sensitivity to modifications of both the bound and continuum wave functions.

Relativistic and non-relativistic descriptions of the removal of a single nucleon from a nucleus using an electromagnetic probe show intriguing differences. Spectroscopic factors obtained through relativistic analyses of $(e, e'p)$ reactions are consistently larger by 10% to 20% than values obtained via non-relativistic analyses[1−4]. In addition, relativistic calculations of the direct knockout contribution to (γ, p) reactions provide a reasonable description of experimental data over a wide range of nuclear targets and photon energies[1,5] while non-relativistic analyses can fall below the data by more than a factor of five[6−8]. The non-relativistic analyses suggest a need for large contributions from meson exchange currents (MEC), while no large MEC contributions are required in the relativistic analyses.

Clearly we can not currently claim to fully understand the reaction mechanisms for these reactions in spite of the relative simplicity of the electromagnetic probes compared to strongly interacting probes. Further experimental guidance is needed, and can be obtained through measurements of spin dependent observables which can provide sensitive tests of the various models for these reactions.

Our models for these reactions retain the fully relativistic treatment of the amplitudes, utilizing solutions of the Dirac equation containing strong vector and scalar

potentials to describe the bound and continuum nucleons. For the $(e, e'p)$ case the amplitude is calculated in the one photon exchange approximation, while for (γ, p) we consider only the direct knockout of the proton[9]. The spectroscopic factor is determined by scaling our calculations of the momentum distributions for $(e, e'p)$ reactions to match experimental data. The same ingredients are then used in our (γ, p) model to perform calculations with *no* adjustable parameters, thus providing *predictions* of calculated observables. One detail to note is that we do not include full Coulomb distortion of the electron wave functions in our model of the $(e, e'p)$ reaction, but choose to use the *effective momentum approximation*[10], in which the magnitude of the electron momentum is modified by the value of the Coulomb potential at the origin, while its direction is unchanged. This provides a large part of the effect of the Coulomb distortion on the electron wave functions for the ^{208}Pb target for the kinematics considered. In our model of the $(e, e'p)$ reaction, the analyzing power due to initially polarized electrons, and the polarization of the final state electrons turn out to be less than 1%. This is likely due to the lack of a proper inclusion of Coulomb distortions.

The proton polarization obtained in this model for $(e, e'p)$ should not be sensitive to this approximation and we have considered this observable in three possible kinematic arrangements used to obtain experimental momentum distributions. In parallel kinematics the polarization tends to be small, showing some structure and an occasional spike but generally remaining under 20%. In both perpendicular and constant $q - \omega$ kinematics, the polarization tends to be large and associated with cross sections large enough to be measurable. An example is shown in FIG. 1, for the case of an oxygen target and an incident electron energy of 700 MeV. The proton kinetic energy is close to 150 MeV in constant $q - \omega$ kinematics. There are two curves showing relativistic calculations, (solid and dashed) for two different optical potentials and a relativistic Dirac-Hartree bound state. The other two curves (dotted and dash-dotted) are from a non-relativistic calculation by Boffi *et al.*[11]. Note that at a missing momentum of 30 MeV/c the calculated proton polarizations can differ by as much as 0.8. In this kinematic region the triple differential cross section is calculated to be about 0.6 $nb/srsrMeV$ and should be readily measurable with the facilities now becoming available.

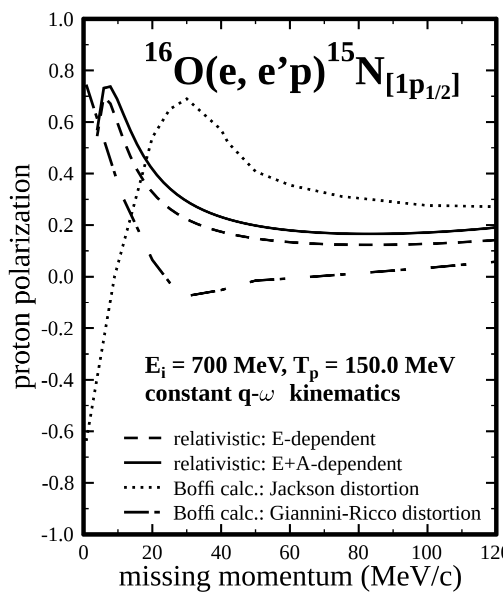

Figure 1: Proton polarization in relativistic and non-relativistic models.

Spin observables for the (γ, p) reaction have also been studied. Calculations have

been done for both photon asymmetry and proton polarization and both observables can be sensitive to the reaction mechanism (i.e. relativistic vs. non-relativistic, or contributions of MECs, Δs), as well as being sensitive to changes in both bound and continuum wave functions for photon energies above 100 MeV. A useful approach would be to measure the spin observables at low photon energies ($E_\gamma \approx$ 80-100 MeV) and over a range of target masses, to try to establish the reaction mechanism in the simplest region. Then measurements through the Δ-region would be very useful in understanding the contributions of MECs and isobars to the reaction mechanism.

The relativistic calculations provide a good description of $(e, e'p)$ and (γ, p) cross section data even at large missing momenta, but measurements of spin observables will provide a more stringent test and would hopefully also clarify the issue of relativistic versus non-relativistic approaches. Measurements of proton polarization in the $(e, e'p)$ reaction will be easiest in perpendicular or constant $q - \omega$ kinematics, where large polarizations can be associated with large cross sections. Photon asymmetry and proton polarization in the (γ, p) reaction are both sensitive to the reaction mechanism as well as the model ingredients.

In short, the reaction mechanism leading to knockout of a single nucleon from a nucleus by an electromagnetic probe is not yet clear, and the additional information provided by measurements of spin dependent observables should strongly constrain the various models for these reactions.

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